

36
5
210
DEC 4 1923

59-5

Proceedings of the American Academy of Arts and Sciences.

VOL. 59, No. 5.—NOVEMBER, 1923.

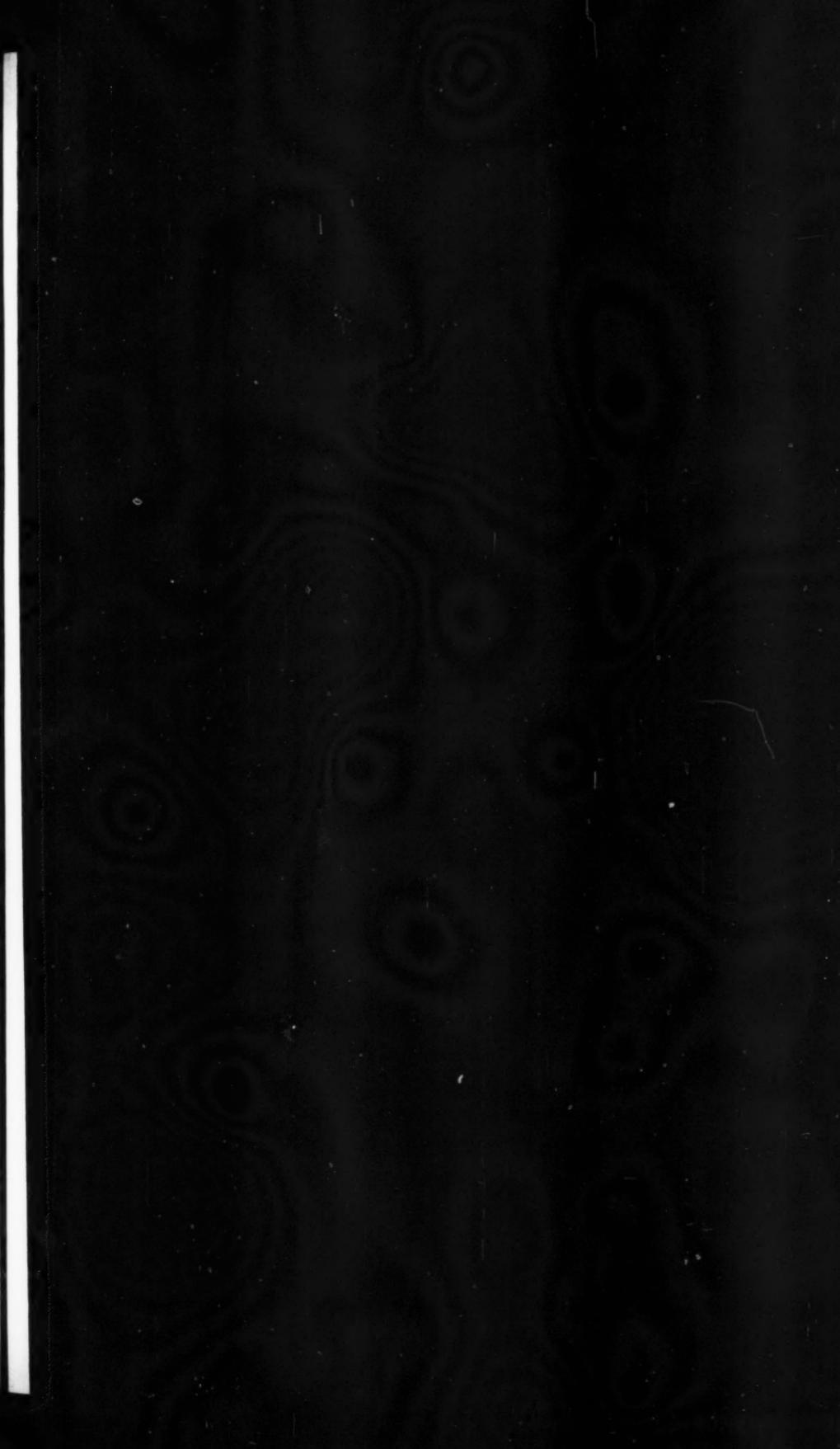
THE COMPRESSIBILITY AND PRESSURE COEFFICIENT OF RESISTANCE OF RHODIUM AND IRIDIUM.

BY P. W. BRIDGMAN.

(Continued from page 3 of cover.)

VOLUME 59.

1. DURAND, ELIAS J.—The Genera Midotis, Ionomidotis and Cordierites. pp. 1-18. 2 pls. September, 1923. \$.80.
2. BAXTER, GREGORY PAUL AND SCOTT, ARTHUR FERDINAND.—A Revision of the Atomic Weight of Boron. The Analysis of Boron Trichloride and Boron Tribromide. pp. 19-48. September, 1923. \$.80.
3. LIPKA, JOSEPH.—Trajectory Surfaces and a Generalization of the Principal Directions in any Space. pp. 49-77. September, 1923. \$1.00.
4. PIERCE, GEORGE W.—Piezoelectric Crystal Resonators and Crystal Oscillators Applied to the Precision Calibration of Wavemeters. pp. 79-106. October, 1923. \$1.00.
5. BRIDGMAN, P. W.—The Compressibility and Pressure Coefficient of Resistance of Rhodium and Iridium. pp. 107-115. November, 1923. \$.50.



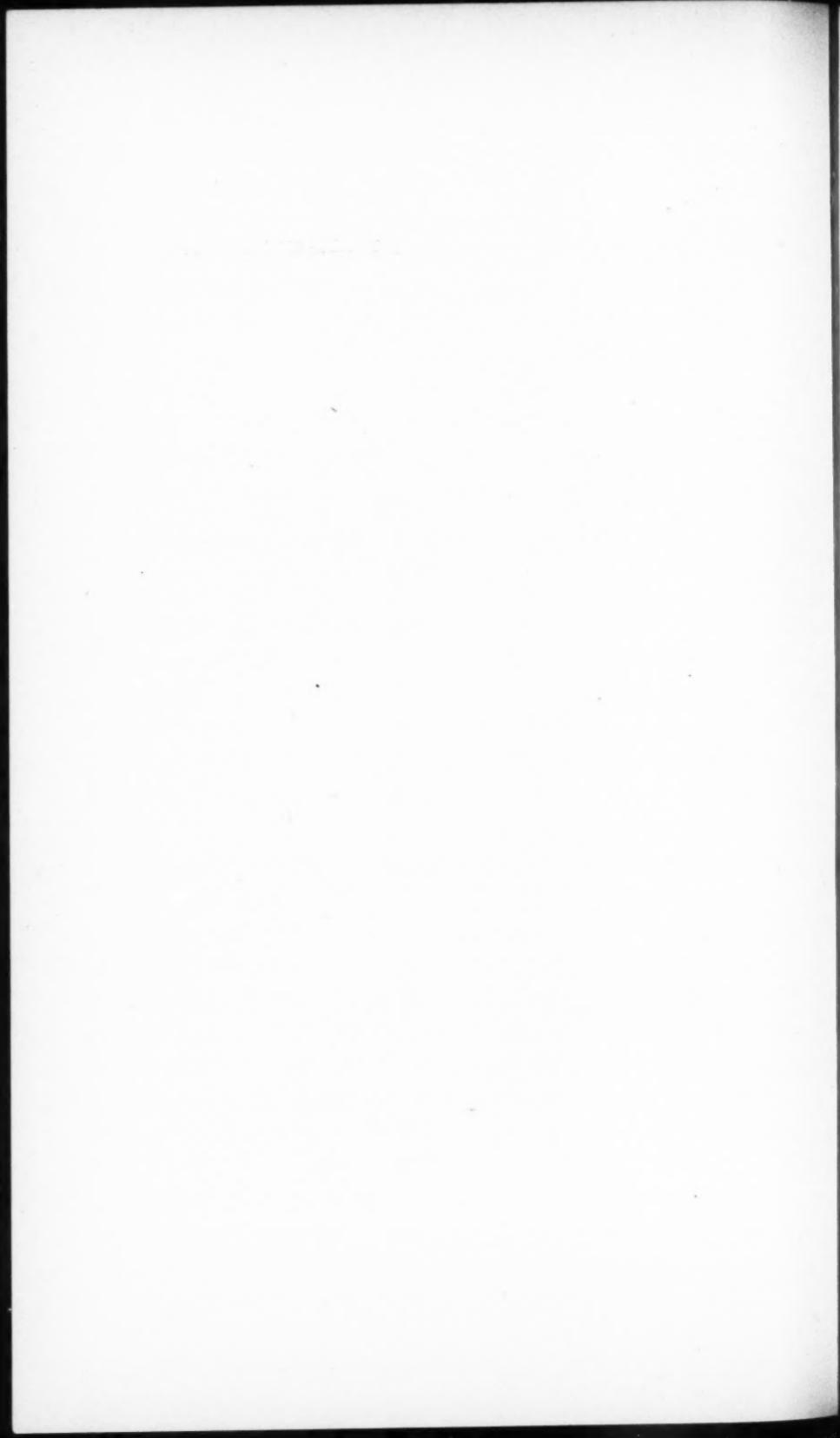


Proceedings of the American Academy of Arts and Sciences.

VOL. 59, No. 5.—NOVEMBER, 1923.

**THE COMPRESSIBILITY AND PRESSURE COEFFICIENT
OF RESISTANCE OF RHODIUM AND IRIDIUM.**

BY P. W. BRIDGMAN.



THE COMPRESSIBILITY AND PRESSURE COEFFICIENT OF RESISTANCE OF RHODIUM AND IRIDIUM.

BY P. W. BRIDGMAN.

Received Oct. 6, 1923.

Presented Oct. 10, 1923.

INTRODUCTION.

THE data of this paper are supplementary to determinations of compressibility and pressure coefficient of resistance which I have previously given for a number of substances.¹ It is my intention to keep this work as up to date as possible by making new determinations either for new materials or else for materials of greater purity than have hitherto been available. I have not hitherto made any measurements on either rhodium or iridium, and I cannot find any records of others, so that these results are quite new.

The two metals were obtained from Johnson and Mathey, London. They were provided in the form of round wires approximately 10 cm. long and 0.08 cm. in diameter. They were shaped by swaging at a red heat, it not being possible to draw them, and therefore they were not perfectly uniform in diameter. The extreme variation from the average diameter of the rhodium was 6.5% and of the iridium 3.2%. Departures from geometrical perfection are entirely without effect on the measurements of pressure coefficient of resistance or of compressibility, but if the departures are too large, the accuracy of the specific resistance, which was determined incidentally, may be somewhat affected. For these two wires, however, the departure from uniformity was so small that no error in the specific resistance is to be feared.

I have no chemical analysis of the materials, but some idea of the probable purity may be obtained from the temperature coefficient of resistance at atmospheric pressure. That of the rhodium is high, and this material is probably as pure as any on which previous measurements (specific resistance and temperature coefficient of resistance) have been published. The temperature coefficient of the iridium, on the other hand, is low, and its purity is probably not as high as might possibly be obtained.

The methods of measuring both pressure coefficient of resistance and compressibility were the same in all respects as those used on other materials, and which have been previously described. The

same apparatus was used, and the usual pressure range of 12000 kg/cm². Resistance was measured by the potentiometer method adapted to specimens of small resistance (the resistance of these specimens was of the order of 0.01 ohm). The current leads and the potential leads were small copper wires soft soldered to the specimen. For the compressibility measurements the specimens were mounted as tension specimens in the lever apparatus for long specimens. Before measurement, the wires were annealed to nearly a white heat in a bunsen flame.

The results follow.

RHODIUM.

Compressibility. The compressibility was measured at 30° and 75°. The points obtained were entirely regular, and all were used in the computation without discarding any. The results are expressed in the formulas:

$$\text{At } 30^\circ, \frac{\Delta V}{V_0} = -10^{-7} [3.72 - 2.67 \times 10^{-5} p] p,$$

$$\text{At } 75^\circ, \frac{\Delta V}{V_0} = -10^{-7} [3.81 - 2.67 \times 10^{-5} p] p.$$

At 30° the average deviation of the 14 observed points from a smooth curve was 0.28% of the maximum observed effect, and at 75° 0.19%. These deviations are on the measured difference of compressibility between rhodium and iron; the corresponding accuracy of the actual compressibility (assuming no error in the value used for iron) is about three times greater.

The compressibility is very nearly the same as that of molybdenum. It is to be noticed that the departure from linearity, shown by the second degree term in the formula above, is greater than it is for iron. This is not usual, and is the first example I have found for a metal, it being the usual rule that the departure from linearity is greater for those metals with the greater compressibility.

Resistance. The electrical resistance was measured as a function of pressure at 30° and 65°. An attempt at 95° did not give good results. The dimensions of the specimen were not as advantageous to accurate measurement of the resistance as of the compressibility, and the results obtained were not as good. The results are expressed in the following formulas, which give the fractional change of resistance at atmospheric pressure and the temperature in question as a function of pressure:

$$\text{At } 30^\circ, \frac{\Delta R}{R_{0,30^\circ}} = -10^{-6} [1.738 - 9.7 \times 10^{-5} p] p$$

$$\text{At } 65^\circ, \frac{\Delta R}{R_{0,65^\circ}} = -10^{-6} [1.776 - 10.1 \times 10^{-5} p] p.$$

At 30° the average departure of the observed points from a smooth curve, (no discards) was 0.60%, and at 65° , 0.95% of the maximum effect.

At atmospheric pressure the specific resistance was calculated from the actual resistance and the dimensions and was found to be 4.90×10^{-6} at 0° . This is somewhat higher than 4.70×10^{-6} , the value found by Broniewski and Hackspill.²

Between 0° and 100° the resistance changes linearly with temperature at atmospheric pressure, and the mean coefficient over this range, in terms of the resistance at 0° , is 0.00399. From the values of Broniewski and Hackspill for the specific resistance I calculate for their temperature coefficient 0.00404. The agreement is within the limit of error indicated by their significant figures.

The pressure coefficient of resistance is of the order of 10% lower than for the other two metals of this class previously measured, platinum and palladium, and the temperature coefficient is slightly higher than for the best platinum, indicating high purity.

IRIDIUM.

Compressibility. The compressibility was measured at 30° and 75° . The results are reproduced in the formulas:

$$\text{At } 30^\circ, \frac{\Delta V}{V_0} = -10^{-7} [2.68 - 1.3 \times 10^{-5} p] p,$$

$$\text{At } 75^\circ, \frac{\Delta V}{V_0} = -10^{-7} [2.81 - 2.2 \times 10^{-5} p] p.$$

The average deviation of the observed points from a smooth line (no discards) was 0.094% of the maximum effect at 30° , and 0.16% at 75° . This deviation is on the difference of compressibility between iridium and iron; the error on the absolute compressibility is about one half of this.

The departure from linearity is here less than it is for iron, which is as to be expected. The variation with temperature of the second degree term is unusually high, as is also the temperature coefficient of the initial compressibility. It will be found on making the computa-

tion that the total change of volume between atmospheric pressure and 12000 kg. is only 1% greater at 75° than at 30°. Possibly the formula gives a temperature variation of both first and second degree terms larger than it should be, one compensating the other.

The absolute compressibility of iridium is smaller than any metal hitherto measured; the lowest value hitherto found was for swaged tungsten, whose absolute compressibility at 30° was 2.93×10^{-7} .

Resistance. The electrical resistance was measured as a function of pressure to 12000 kg/cm² at 30°, 65°, and 95°. The results are reproduced by the formulas:

$$\text{At } 30^\circ, \frac{\Delta R}{R_{0,30^\circ}} = -10^{-6} [1.353 - 4.0 \times 10^{-6} p] p,$$

$$\text{At } 65^\circ, \frac{\Delta R}{R_{0,65^\circ}} = -10^{-6} [1.280 - 3.9 \times 10^{-6} p] p,$$

$$\text{At } 95^\circ, \frac{\Delta R}{R_{0,95^\circ}} = -10^{-6} [1.340 - 3.9 \times 10^{-6} p] p.$$

At 30° the deviation from a smooth curve of the observed points (no discards) was 0.8% of the maximum effect, at 65° it was 1.1%, and at 95° 2.1%. The formulas show that the initial coefficient has a minimum value at 65°. This is unusual, but other examples have been found. The temperature variation seems to be outside the limits allowed by the probable error, and is probably real for this material. Whether it would be found for absolutely pure iridium is another question.

The pressure coefficient of resistance is materially lower than that for rhodium, as would be expected from its smaller compressibility and higher melting point, and is close to that previously found for tungsten.

The specific resistance at atmospheric pressure, found from the measured resistance and the dimensions, was 6.61×10^{-6} ohms per cm. cube, considerably higher than 6.10×10^{-6} , the value of Broniewski and Hackspill.²

The temperature coefficient of resistance at atmospheric pressure between 0° and 100° I found to be 0.00322. The relation between temperature and resistance is not quite linear, but the average coefficient between 0° and 50° is 0.8% less than between 0° and 100°. This is the normal direction for departure from linearity, and is the reverse of the direction shown by platinum. I calculate from the values of Broniewski and Hackspill for the specific resistance that the temperature coefficient of their iridium between 0° and 100° was 0.00361.

This is too much above my value to be accounted for by errors of measurements, and doubtless indicates a perceptible amount of impurity in my iridium. The effect of this impurity on the compressibility is probably very small, on the pressure coefficient of resistance somewhat larger, and on the temperature coefficient of resistance largest of all, bringing the value from 0.0032 to somewhere around 0.0040. It is to be anticipated, judging from experience with other metals, that the compressibility of pure iridium will be slightly less than the value given above, and the pressure coefficient of resistance somewhat greater numerically.

DISCUSSION.

A comparative study of the properties of the three series of chemically related elements Fe, Co, Ni; Ru, Rh, Pd; and Os, Ir, Pt is of interest. In Table I are collected various data for these elements, namely atomic weight, melting point, atomic volume, compressibility at 30°, and pressure coefficient of electrical resistance at 30°. The two latter data are missing for Os and Ru. The table discloses irregularities in the progression of the properties; what the exact significance of these irregularities is I shall not attempt to discuss. In the first place the order of atomic weights in the first series is not the same as that of the atomic numbers, as is well known, there being an inversion between Co and Ni. This inversion is not found in the other two series, but it will be noticed that in the second series the difference of atomic weights between Ru and Rh is much less than between Rh and Pd, whereas in the third series the atomic weights are almost exactly evenly spaced. There is here evidently some sort of progressive change as the outer electron structure of the atom becomes more complicated. In each series the melting point progresses regularly, being least for the member with greatest atomic number. The atomic volumes, on the other hand, do not progress regularly, but there is a reversal in passing from the light to the heavy series; in the first series the lightest member has the greatest volume, and in the third the heaviest, the order being irregular in the second series. The compressibility also shows no regular order, but does follow the order of atomic volumes as far as the data are known, the element with the greatest atomic volume in any series also having the greatest compressibility, which is what would be expected. This would lead us to expect that the compressibility of Os would be even smaller than that of Ir, and the smallest known for a metal. It is even not unlikely that

TABLE I.

	Fe	Co	Ni
Atomic weight	55.84	58.97	58.68
Melting point	1530° C	1480	1452
Atomic volume	7.1	6.8	6.7
Compressibility at 30°	5.87×10^{-7}	5.39×10^{-7}	5.29×10^{-7}
Pressure coefficient of resistance at 30°	-2.42×10^{-6}	-9.3×10^{-7}	-1.90×10^{-6}
	Ru	Rh	Pd
Atomic weight	101.7	102.9	106.7
Melting point	2450?	1950	1550
Atomic volume	9.0	8.5	9.2
Compressibility at 30°		3.72×10^{-7}	$5.19 \} \times 10^{-7}$ $5.28 \}$
Pressure coefficient of resistance at 30°		-1.74×10^{-6}	-1.96×10^{-6}
	Os	Ir	Pt
Atomic weight	190.9	193.1	195.2
Melting point	2700	2350	1755
Atomic volume	8.5	8.6	9.2
Compressibility at 30°		2.68×10^{-7}	$3.60 \} \times 10^{-7}$ $3.05 \}$
Pressure coefficient of resistance at 30°		-1.35×10^{-6}	-1.95×10^{-6}

it may be less than for diamond. The pressure coefficient of resistance in each of the series decreases numerically from the third to the second member of the series. In the Fe, Co, Ni series the coefficient increases again on passing from Co to Fe; the data have not yet been obtained to show whether the behavior in the other two series will be the same.

SUMMARY.

Measurements by previous methods of compressibility and pressure coefficient of electrical resistance have been extended to rhodium and iridium. The compressibility of rhodium is about that of molybdenum, and that of iridium is somewhat less than that of tungsten, and is the lowest yet measured for a metal. The pressure coefficient of resistance of rhodium is of the order of that of platinum and palladium, and that of iridium is close to that of tungsten. Measurements are also given of the specific resistance at 0° and the mean temperature coefficient of resistance between 0° and 100° at atmospheric pressure. In the discussion attention is called to certain irregularities in the progression of properties in the three chemically related series Fe, Co, Ni; Ru, Rh, Pd; Os, Ir, Pt.

I am indebted to my assistant Mr. I. M. Kerney for making many of the readings.

THE JEFFERSON PHYSICAL LABORATORY,
Harvard University, Cambridge, Mass.

REFERENCES.

- 1 P. W. Bridgman, Proc. Amer. Acad. **52**, No. 9, 1917; **56**, No. 3, 1921; **58**, No. 4, 1923; **58**, No. 5, 1923.
- 2 Broniewski et Hackspill, C.R. **153**, 814-816, 1911.



